REMOTE SENSING APPLICATIONS IN FORESTRY

THE IDENTIFICATION AND QUANTIFICATION OF PLANT SPECIES, COMMUNITIES AND OTHER RESOURCE FEATURES IN HERBLAND AND SHRUBLAND ENVIRONMENTS FROM LARGE SCALE AERIAL PHOTOGRAPHY

By

Richard S. Driscoll
Jack N. Reppert

Rocky Mountain Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture

Annual Progress Report 30 September, 1968

A report of research performed under the auspices of the
FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—
A Coordination Facility Administered By
The School of Forestry and Conservation,
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For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

This is the first annual progress report of a study to assess the merits of large scale color and infrared color aerial photography to detect and identify herbaceous and shrubby plant species and communities. The work was initiated in April 1968 and includes research at four test locations representing highly contrasting herbland and shrubland environments in Colorado.

Detailed ground-truth data were collected at each location. These included foliage cover by plant species, state of growth, color of plant material, and ground surface characteristics such as amount and kind of exposed soil, soil surface colors, and amount and kind of plant litter. In addition, replicates of plant species and the location of line transects used to measure the vegetation and soil surface parameters were so marked that they were easily detected in the aerial photographs. Ground photography using 35mm Kodachrome X, 35mm Ektachrome Infrared Aero (type 8443) and 4 x 5 Polaroid Polapan type 52 film were exposed to be used for reference aids in aerial photo interpretation and the development of photo interpretation keys.

Three photo missions--June 1, July 2 and August 5, 1968--over three test locations provided simultaneous photography using Anscochrome D-200 and Ektachrome Infrared Aero (type 8443) with a 70mm format at scales of approximately 1:600, 1:1200 and 1:2400. Two photo missions--July 2 and August 5, 1968--over a fourth test location, provided similar photography. An additional overflight is scheduled for two of the test locations on approximately October 1, 1968.

Ground truth data are now being processed in preparation for developing techniques for photo interpretation by use of a General Aniline and Film Corporation Model 650 Microdensitometer and peripheral equipment. These results are not yet available.

A narrative dichotomous photo interpretation key has been developed using 1:920 scale infrared color photographs of the mountain grassland test location on August 24, 1967. Image characteristics most useful to date include: (1) general color, (2) pattern and texture, (3) relative size, shape and shadow, and (4) specific color of the object. Additional testing needs to be done to assess the validity of the key and representative stereograms need to be selected to illustrate the objects.

The potential staging of the type of aerial photography used in this study to date to that procured from earth orbiting satellites for the detection, qualification, quantification and surveillance of herbland and shrubland resources is discussed.

ACKNOWLEDGMENTS

This research was conducted under the Manned Earth-Orbital Experiment Program in Agriculture/Forestry under the sponsorship and financial assistance of the National Aeronautics and Space Administration, Contract No. R-09-038-002. This is the first annual report of a cooperative program with the Forest Service, U. S. Department of Agriculture, and involves two Forest and Range Experiment Stations: the Rocky Mountain at Fort Collins, Colorado, and the Pacific Southwest at Berkeley, California. Salaries of all professional employees are being contributed by the Forest Service.

Special appreciation is extended to Dr. O. C. Wallmo, Principal Wildlife Biologist, to Dr. P. O. Currie, Range Scientist, both of the Rocky Mountain Forest and Range Experiment Station, and to Mr. R. B. Gill, Research Biologist, Colorado Game, Fish and Parks Department, who contributed their talents and resources in the conduct of this research.

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THE IDENTIFICATION AND QUANTIFICATION OF PLANT SPECIES, COMMUNITIES, AND OTHER RESOURCE FEATURES IN HERBLAND AND SHRUBLAND ENVIRONMENTS FROM LARGE SCALE AERIAL PHOTOGRAPHY

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INTRODUCTION

The growing and grazing of livestock for food and clothing has been documented in world history since the beginning of recorded civilization. The demand for these products continues to expand with increases in the world population and as knowledge of human nutritional requirements is refined. In the United States alone, the per capita consumption of beef increased from 85.4 pounds in 1956 to 103.8 pounds per year in 1966. (U. S. Dept. Agric. 1967). Based on population growth predictions in the United States, from 200 million people in 1968 to 242 million people in 1980, this 20 percent increase in consumer demand must be expected with a consequent increased demand for grazing on all range lands of which native herbland and shrubland are major components. Although grazeable herbage on these and similar areas throughout the world is a renewable natural resource, management must be judicious to avoid destruction of the range resource or deleterious effects to associated resources including soil, water and timber.

Much of these rangelands, nearly one billion acres in the United States, is relatively inaccessible and subject to dynamic changes in land use as well as vegetational changes caused by excessive grazing, fire, or epizootic outbreaks. Management of these lands to assure the greatest

economic and aesthetic benefits without destruction of the vegetation or soil is becoming increasingly complicated as demands for land use intensify. Consequently, resource inventory methods to provide knowledge of the location, kind and amount of vegetation available for use as well as a monitoring system that will detect habitat changes over time, but requiring minimum ground searching, is required for management decisions.

Ground survey methods alone are too slow and costly considering the relative inaccessibility of the vast expanses of land involved. Since aerial photographs contain much detailed information about the terrain and the vegetation thereon, the only practical way to provide accurate rangeland resource inventories and to keep such large areas under surveillance is by some combination of aerial and ground technique. If an airborne-ground technique can be developed, utilizing photography procured at various scales staged with multiple sampling procedures, the next step upward--a space vehicle platform--may provide extensive and repetitive coverage needed for rapid and accurate inventories provided acceptable resolution capabilities are realized by spacecraft camera systems.

This report presents preliminary information on research initiated in April 1968 under the current financial arrangement and includes some results of prefatory investigations conducted during 1967 with Forest Service research appropriations.

STATUS OF KNOWLEDGE

Standard panchromatic aerial photographs at scales of approximately 1:15,000 to 1:20,000 have been accepted as an essential asset to assist in herbland and shrubland inventories. Over thirty years ago, it was stressed that reliable base maps were essential for detailed range

surveys and that these base maps could be derived through use of aerial photography (Interagency Range Survey Committee, 1937). Burks and Wilson (1939) described a vegetation inventory procedure using aerial photographs. Harris (1951) became more sophisticated and described a method whereby aerial photographs could be used in conjunction with subsampling procedures on the ground to improve range inventory techniques. This type of photography was used primarily to delineate broad vegetation types and locate cultural features such as water sources, fences and roads. However, identity of individual plants or community types and the position of vegetation type boundaries are frequently difficult to determine on black and white photographs except possibly by expert aerial photograph interpreters. This is due in part to the fact that only about 200 shades of gray can be distinguished on panchromatic prints and only a few of these are readily verified by most observers using such photography (Swanson, 1964).

Color aerial photography offers greater possibilities to detect and identify specific objects in herbland and shrubland environments. The three color dimensions, hue, value and chroma, provide greater photo interpretative characteristics of objects than do merely shades of gray observed in black and white photographs. The introduction of color infrared sensitive film introduces still an additional feature. Properly exposed and filtered, this film type provides image signatures on film from a portion of the electromagnetic spectrum not observable to the human eye (0.7 to 0.9 micron wavelength band). That such photography frequently registers differences among objects not visible or difficult to see on conventional photography has been demonstrated when dealing

with forests and croplands (Heller, 1965; Colwell, 1961).

Simultaneous interpretation of aerial photographs procured from different film types sensitive to different parts of the spectrum should provide more information about the herbland and shrubland environments than is obtained when using only one film type. Each object or condition in nature has a unique distribution of absorbed, emitted and reflected energy. When dealing with a plant species or community, this characteristic changes depending on the growth cycle of the plant as related to phenology or some physiological stress. This concept of multiband reconnaissance has been advanced by Colwell (1961) as a way whereby a greater number of features could be detected and identified when two or more film types procured from different sensors were interpreted in unison.

Specific research objectives of this study are to determine latent capabilities of color and color infrared aerial photography to detect and identify plant species and communities in herbland and shrubland environments and to devise photogrammetric techniques to estimate plant cover and density. Problems to be solved include (1) determination of optimum scales and seasons of photography, and (2) development of ground-photo measurement systems that might be programmed through a microdensitometer or similar film scanning system to provide for automatic data processing.

LOCATION AND DESCRIPTION OF THE STUDY AREAS

Four test locations are being used for this study (Fig. 1). These areas were selected because of the variety of plant species and communities representing diversified conditions in the generalized herbland and shrubland vegetation types. In addition, on-going research related to other problems and conducted by other scientists in these areas provided

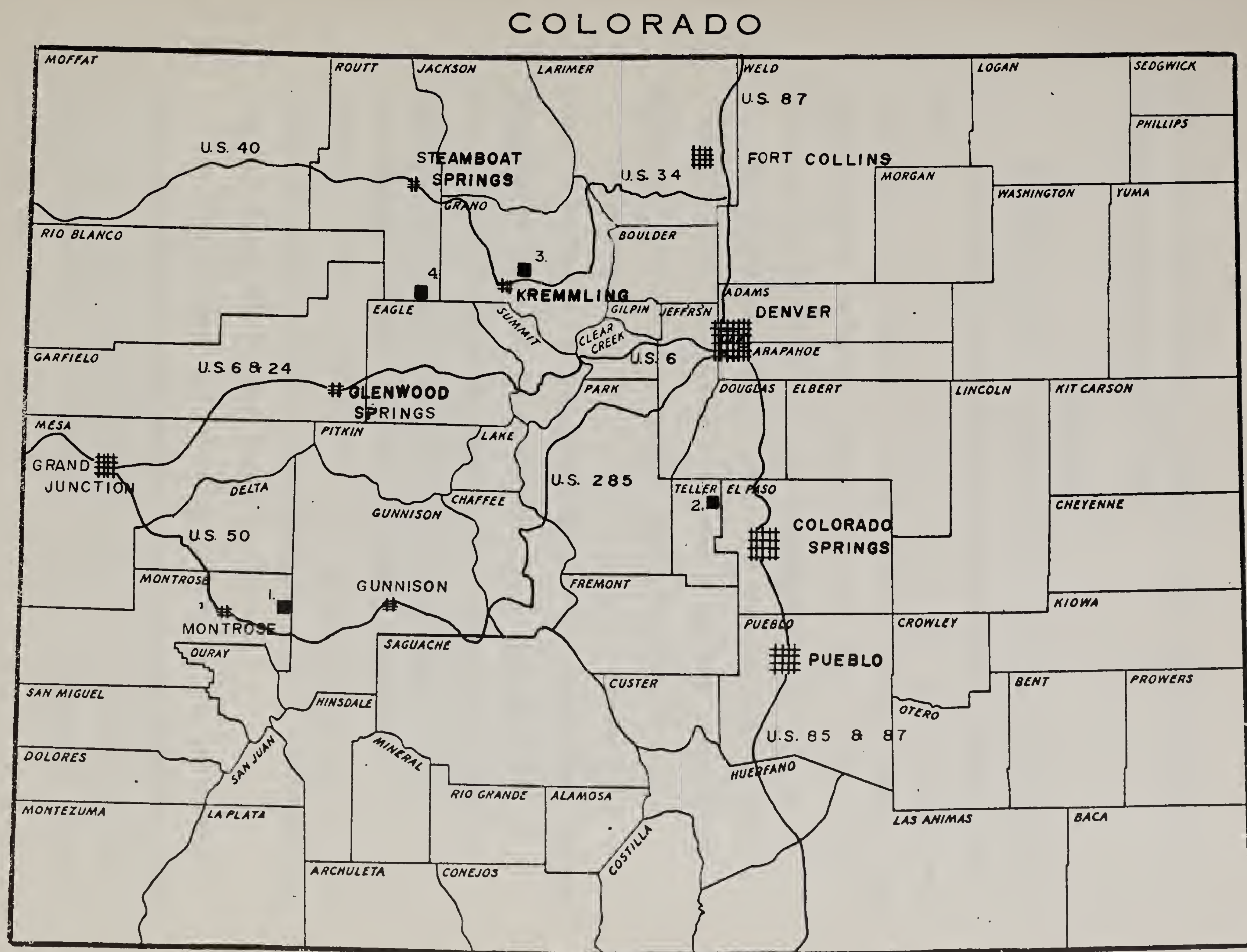


Figure 1. Location of the study areas: 1. Black Mesa: Mountain grassland; 2. Manitou: Ponderosa pine bunchgrass type; 3. Kremmling: mixed shrub type; 4. McCoy: Pinyon-juniper woodland with shrubby understory.

some ground truth information regarding kinds, amount and location of various plant species and communities.

Black Mesa

The Black Mesa test location occurs on the Gunnison National Forest and is approximately 30 airline miles west of Gunnison, Colorado. The elevation of this location ranges from 9720 to 8711 feet above mean sea level. The area is typical of the high mesas and plateaus common to the western slope of the central Rockies and is generally typical of high mountain parklands throughout the Rocky Mountains.

The generalized vegetation pattern of the area (Fig. 2) consists of mountain parks interspersed with groves of engleman spruce (*Picea engelmanni* Parry) and aspen (*Populus tremuloides* Michx.).

The herbaceous vegetation in the parks and on the test site is primarily Thurber fescue (*Festuca thruberi* Vasey), Idaho fescue (*Festuca idahoensis* Elmer), letterman needlegrass (*Stipa lettermanii* Vasey), Aspen fleabane (*Erigeron macranthus* Nutt.), wild geranium (*Geranium fremontii* Torr.), orange sneezeweed (*Helenium hoopesii* A. Gray), tall lupine (*Lupinus* L.) and valeriana (*Valariana acutiloba* Rydb.). The two most common shrubs are parry rabbitbrush (*Chrysothamnus parryi*) (A. Gray) Greene) and shrubby cinquefoil (*Potentilla fruticosa* L.), although these plants are not abundant except in local colonies.

The area has been used for controlled range cattle grazing experiments conducted by the Rocky Mountain Forest and Range Experiment Station since 1954. Yearling Hereford heifers are grazed from about July 15 to approximately October 1. In addition, mule deer and elk graze the area

Figure 2. The Black Mesa test location near Gunnison, Colorado, is a mountain grassland interspersed with groves of engleman spruce and aspen. Thurber fescue, Idaho fescue, aspen fleabane and wild geranium are important herbaceous species. Elevation is approximately 9800 feet.

freely from the time of snowmelt in the spring to the advent of snow cover in the fall. Mountain pocket gophers, burrowing rodents are common throughout the area.

The soils of the area are mostly residual, derived from felsitic material. Soil surface colors, according to Munsell color notations, are dark grayish brown (10YR4/2 dry) and dark brown (10YR3/3 moist) with some slightly lighter or slightly darker local variations. The soils are relatively high in organic matter with loamy textures.

Precipitation averages about 25 inches per year with about two-thirds falling as snow from November through April and one-third occurring as spring and summer rain showers. Temperatures are relatively low and the growing season is generally limited to June, July and August. Severe frosts are likely to occur any month.

Manitou

The Manitou site (Fig. 3) occurs approximately 25 airline miles northwest of Colorado Springs, Colorado, and is within the Pike National Forest. The area is located in a broad mountain valley characteristic of many in central Colorado. The elevation of the site is 7700 feet.

The vegetation of the area is generally referred to as the Ponderosa pine-bunchgrass type typical of much of the lower montane zone along the eastern slope of the Rockies. Ponderosa pine (*Pinus ponderosa* Laws.) occurs throughout the area in open to dense stands; these stands are interspersed with untimbered parks. The specific test site is located in one of these untimbered parks.

Perennial grasses on this test location consist primarily of blue gramma (*Bouteloua gracilis* (H.B.K.) Lag.), Arizona fescue (*Festuca arizonica*

Figure 3. The Manitou test location near Colorado Springs, Colorado. This is a Ponderosa pine/bunchgrass type used by range cattle from June to October. Arizona fescue, mountain muhly and blue grama are important forage species. Elevation is approximately 7700 feet.

Vasey), and mountain muhly (Muhlenbergia montana (Nutt.) Hitchc.). The most abundant forbs are pussytoes (Antennaria sp. Gaertn.), fringed sagebrush (Artemisia frigida Dougl.), training fleabane (Erigeron flagellaris A. Gray), and Pennsylvania cinquefoil (Potentilla pennsylvanica L.). No shrubs occur in the area.

The soils of the area have been developed from alluvial deposits of Pikes Peak granite of which the principal components are quartz and large orthoclase crystals. They are reddish brown (5YR4/4 dry to dark brown 7.5YR3/2 moist), low in organic matter, and loose with a sandy loam texture.

Precipitation averages about 15 inches per year with 75 percent occurring from April through September. During July and August, many high intensity storms occur as a result of convectional thermal systems.

The test location has been used for controlled range cattle grazing experiments by the Rocky Mountain Forest and Range Experiment Station since 1941. Currently, the area is being used by Hereford cows and calves from June through October under a planned range recovery study. This work, under the direction of Dr. P. O. Currie of the Rocky Mountain Station, involves cultural treatments using fertilizer and herbicides combined with seasonal grazing in small paddocks to enhance range recovery. This was a reason for locating on this site and was in addition to the fact that plant species and community identifications and quantifications had been made. This combination of favorable factors greatly facilitated the making of preliminary investigations on possible previsual detection of physiological imbalances on important herbland plant species through the use of remote sensing techniques. The analysis of various cultural

treatments by means of remote sensing also was facilitated.

In addition to cattle, the area is used by mule deer, jack rabbits, ground squirrels and gophers.

Kremmling

The Kremmling site is located approximately 10 miles ENE of Kremmling in northcentral Colorado. The area occurs within a very broad mountain valley. The elevation of this site ranges from 8000 to 8100 feet above mean sea level.

The vegetation of this area is a mixed shrub type (Fig. 4). The more abundant shrubs include big sagebrush (*Artemisia tridentata* Nutt.), rothrock sage (*Artemisia rothrockii* A. Gray), rabbitbrush (*Chrysothamnus lanceolatus* Nutt.), broom snakeweed (*Gutierrezia sarothrae* (Pursh.) Britt. and Rusby), bitterbrush (*Purshia tridentata* (Pursh) D.C.), and snowberry (*Symphoricarpos* spp. Duhamel.). The must abundant herbaceous species include bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. and Smith), wild buchwheat (*Eriogonum subalpinum* Greene), junegrass (*Koeleria cristata* (L.) Pers.), bluebell (*Mertensia* spp. Roth.), phlox (*Phlox* sp. L.), and squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith).

The soils of the area have been developed from ancient lacustrine deposits with the surface textures ranging from silt loam to sandy loam. They are dark gray brown (10YR4/2 dry) to very dark gray brown (10YR3/2 moist) on the surface and have moderate amounts of organic matter. Some of the soils crack on the surface upon drying.

Precipitation averages about 12 inches per year with about 60 percent falling from May through September. Subzero Fahrenheit temperatures are common during winter months and the summer climate is cool.

Figure 4. The Kremmling test location. This is a mixed shrub type occurring within a broad inland valley at an elevation of approximately 8000 feet. Two species of sagebrush, rabbitbrush, snakeweed, bitterbrush and snowberry are the most abundant shrub species. The area is grazed by range cattle during the spring-summer-fall season and is grazed heavily by mule deer during most winters.

This test location is grazed by range cattle under Government permit during the spring, summer and fall. The area is grazed heavily by mule deer in the winter during most years. Ground squirrels are common rodents in the area.

McCoy

The McCoy site is located approximately 25 airline miles southwest of Kremmling. It occurs within a complex rolling to hilly topographic pattern within a wide expanse of the upper Colorado River Drainage. The elevation of the area is approximately 7400 feet.

The general vegetation of the area is an open pinyon-juniper woodland with a shrubby understory (Fig. 5). Pinyon pine (Pinus edulis Engelm.) and Rocky Mountain juniper (Juniperus scopulorum Sarg.) are common. Shrubby species include mountain mahogany (Cercocarpus montanus Raf.), big sagebrush (Artemisia tridentata Nutt.), and prickleypear (Opuntia polycantha Haw.). The most common herbaceous species are bluebunch wheatgrass (Agropyron spicatum (Pursh) Scrib. and Smith), indian ricegrass (Oryzopsis hymenoides (R. & S.) Ricker), squirreltail (Sitanion hystrix (Nutt.) J. G. Smith), phlox (Phlox spp. L.) and beardtongue (Penstemon spp. Mitchell).

The soils of the area are very complex. They are mostly residual in origin, developed from sandstone or limestone, and have sandy loam to sandy clay loam surface textures. Surface colors include Munsell hues of 5R, 10R and 5YR. For the most part, they are weak red (10R 4/3 to 4/4 dry).

Precipitation averages approximately 12.5 inches per year with approximately 50 percent occurring from June through September. The air temperature regime is similar to that of the Kremmling site.

[illegible]

Figure 5. The open pinyon-juniper woodland vegetation type at the McCoy test location. In addition to the trees, mountain mahogany and big sagebrush are important parts of the vegetation complex. Herbaceous species are relatively minor. The area is used by range cattle and sheep throughout the year. Elevation is approximately 7400 feet.

This test location is used by range cattle, sheep and deer throughout the year. The area experiences heavy use on most forage and browse species most of the time and experiences severe mortality of deer in some winters.

METHODS

Precise ground control was required in this study to provide: (1) aircraft flight orientation, (2) reference sources for positive detection and identification of various objects imaged in resultant aerial photography, and (3) ground measurements for use in development of photo mensuration techniques.

Ground Procedures

Ground Markers for Flight Orientation

Flight lines varying from 250 to 4500 feet were established on the test locations to assure photographic coverage of specific kinds of plants and plant communities. At Black Mesa, Kremmling and McCoy, one line was established at each location. Nine lines were established at the Manitou location.

Various kinds of ground markers were used to assure accurate photographic coverage of the twelve flight lines. At the beginning and end of all flight lines, except at the Manitou location, ground panels of white paper strips, arranged in the form of a cross and spaced a known distance apart (Fig. 6), were used for aircraft orientation during photography and to determine photo scale. At Manitou, similar paper strips, but arranged in the form of a "T", marked the beginning and end of each flight line. Also, single strips of paper were anchored to the ground and oriented parallel to the flight lines between the primary markers for added flight

control. Where trees along the flight lines potentially obscured on-the-ground markers, white or red flags were erected in trees to guide the pilot. Ground-air radio communication was established by use of the Forest Service air-net radio system.

Plant Species Identification

At each test location, various numbers of different plant species and other objects were marked on the ground to provide reference material for positive identification of the objects in the aerial photography (Fig.7). White or yellow painted wooden surveyor stakes served this purpose.

The position of each stake was marked on the ground to assure re-location of the same object for each photo mission. This was accomplished by leaving nails in the ground to mark the location of holes bored in the stakes or by mapping to reference the distance of the object from a fixed point such as a metal plot marking stake.

Ground photography of selected items was secured for each photo mission to provide further reference material for positive identification of items imaged in the aerial photography (Fig. 8). This included vertical shots from a stepladder using 35mm Kodachrome X and Ektachrome Infrared Aero (type 8443) six to ten feet above the ground (Fig. 9). In addition to providing information on the location of specific items on the ground, this photography recorded changes in relative color, pattern, texture, size, shape and shadow of these items at various times during the growing season (see Figs. 9, 10) to be used for developing subsequent photo interpretation keys.

This ground marking and photography procedure included 10 replicates of each of 2 shrubs, 2 bunchgrasses and 6 forbs at Black Mesa. At Manitou,

a. Kodachrome X

Ektachrome Infrared Aero

Figure 7. Surveyor's stakes anchored to the ground and visible in the aerial photography were used to mark individual species for reference material for positive identification in the aerial photographs. The arrow points to rothrock sage at the Kremmling location. Both color (a) and infrared color (b) exposures from the ground were made to reference to the two kinds of aerial photography for interpretation.

Figure 8. Ground photography (including 35mm Kodachrome X, 35mm infrared color and 4 x 5 panchromatic films) was obtained from a stepladder at the time of each photo mission of specific plant species and areas at each study location. This is used for reference material for interpretation of the aerial photographs secured at each photo mission.

a. Kodachrome X - 7/1/68

c. Kodachrome X - 8/6/68

b. Ektachrome Infrared Aero - 7/1/68

Figure 9. Ground photographs using both color and infrared color were made for each photo mission to provide specific information on location of the target objects and relative changes in color, pattern, texture, size, shape and shadow of the objects. Note the size and phenology change of sneezeweed (top, right arrow) from vegetating growth to full blooming flowers from a. to c. on the Black Mesa area. Also, relative density of vegetation increased from a. to c. during the one-month time lapse in photography. Photographs a. and b. indicate the switch in color rendition of target objects comparing films sensitized to the visible spectrum (0.3 to 0.7 microns) as compared to near infrared (0.5 to 0.9 microns).

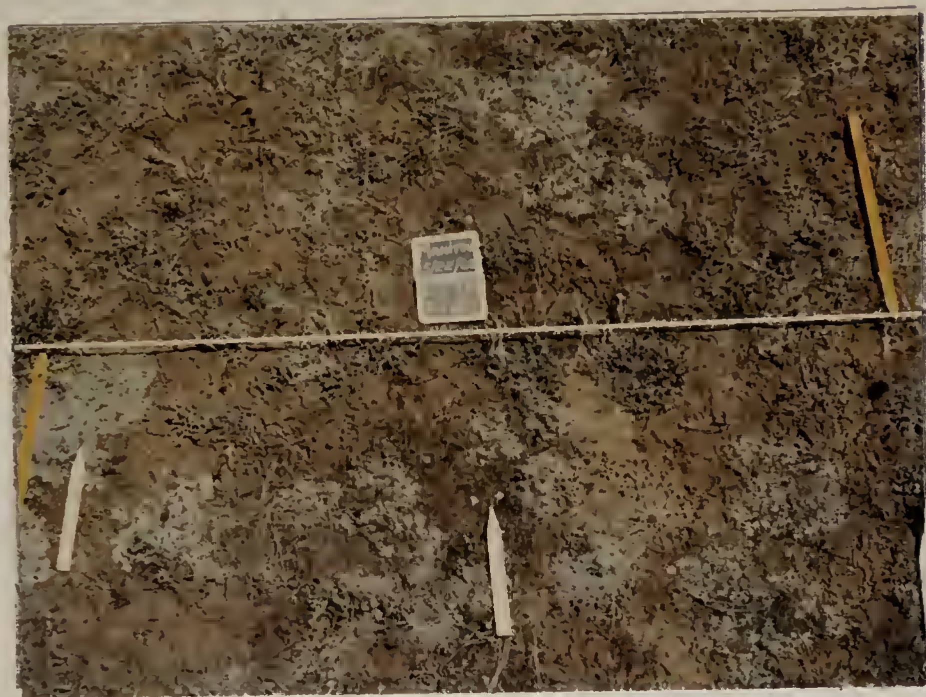
8 replicates in each of 5 blocks representing different cultural treatments were marked to include 3 grasses and 3 forbs. At Kremmling, 10 replicates of 7 shrubs, 10 replicates of 3 forbs, 5 replicates of 4 bunchgrasses, and 5 replicates of 1 forb were marked. At the McCoy location, 5 replicates each of small pinyon pine and juniper, 5 replicates of 1 shrub, and 5 replicates of two herbaceous species were included. In addition, from 5 to 20 replicates of other items such as soil surface disturbances caused by rodents were marked and photographed at each test location.

Plant Species and Community Measurements

At all locations, ground measurements of plant cover, plant litter, bare soil and soil surface stoniness were made along established line transect locations within a week of each scheduled photo mission. Measurements were made at a vertical view angle above the transect to duplicate a similar view position as observed in the aerial photography. The procedure followed was that described by Canfield (1950) whereby the distance along an established line on the ground intercepted by a specific object is charted on cross-section paper.

The locations of these transects were marked on the ground with surveyor's stakes or pointed lath so their relative positions could be detected in the aerial photography (Fig. 10, and see Figs. 11, 12 and 13). The transect locations were marked for future relocation by the same method as described under Plant Species Identification to facilitate measurement at each photo mission. This was necessary to provide information on the seasonal dynamics of vegetation as related to the "best" time for photography for herbaceous and shrubby photo identifi-

Figure 10. Transect locations were marked on the ground with pointed lath or surveyor's stakes so the transect position could be seen in the aerial photographs. Individual target objects were also marked and referenced to position along the transect line to facilitate positive identification of these items in the aerial photographs.



a. Kodachrome X - 5/22/68

c. Kodachrome X - 8/8/68

b. Color Infrared - 5/22/68

Figure 11. Line chart transect locations were so marked on the ground to facilitate relocation and measurement of the same area on aerial photographs secured from each photo mission. This illustrates the single line transect system established at the Manitou test location. Ground photography using both color and color infrared film types was secured to record the visual seasonal change in vegetation in the transect area to be referenced to the aerial photographs. Apparent plant size increased from 5/22 to 8/8 (compare a. and c.) as a result of increased foliage growth at the Manitou area. Similar changes occurred at the other test locations (see Figs. 9 and 12).

cation and mensuration (Fig. 11, and see Figs. 9 and 12). Measurements made of these ground transects will be related to scan line readouts produced by a General Aniline and Film Corporation Model 650 microdensitometer of the same transect locations imaged on the photography. This procedure will in turn provide a first step in developing automatic interpretation and data processing using a remote sensing procedure.

Ground photography was secured of the transect layouts. In addition to using 35mm Kodachrome X and Ektachrome Infrared Aero (type 8443), black and white Polaroid film (polapan type 52) was exposed to provide an instantaneous map of the transect area to assist in the development of photo interpretation keys, to facilitate interpretation of GAF microdensitometer line-scan readout to on-the-ground measurements, and to assist in relocation of plant species and transect markers.

At Black Mesa, eleven clusters of four 6-meter long transects were established. Each transect cluster was systematically arranged in a 6-meter square sampling plot which represented a particular plant community (Fig. 12). At Kremmling, eight clusters of transects were similarly established (Fig. 13). These plots facilitated density counts of plants as well as intercept measurements. At McCoy, 38 30-meter long transects were established along the center of the flight line. These transects represented a continuum from dense to sparse stands of shrubs and pinyon-juniper woodland. At Manitou, 20 20-foot long transects were used to measure line intercept. These units had previously been established for plant measurements relative to the on-going study under the direction of Dr. Currie.

All flight line, plant species, and transect markers were placed on and removed from the ground immediately prior to and after the

a. Kodachrome X - 7/1/68

b. Kodachrome X - 8/6/68

Figure 12. Four 6-meter long transects were established in each of eleven plots at the Black Mesa test location. Line intercepts by plant species, species groups, and soil surface characteristics are made on the ground. These are compared to microdensitometer scan-line readouts as part of the development of automatic interpretation and data processing techniques using large scale aerial photographs.

Figure 13. At the Kremmling location, eight clusters of four 6-meter transects were marked on the ground. These clusters represent different plant communities. In addition to line intercept measurements, data on the density (numbers) and distribution (spatial distance) of shrubs were obtained for correlating with similar measurements made on the aerial photographs.

scheduled photo missions, respectively, to avoid disturbances from animals and weather and to prevent littering the landscape.

Aerial Photography

As mentioned in the Status of Knowledge, panchromatic aerial photography at scales of 1:15,000 to 1:20,000 is an accepted part of herbland and shrubland inventory procedures--used primarily as a map base for delineation of broad vegetation types. Since it is difficult and frequently impossible to discriminate individual herbaceous and many shrubby species in this type of photography, color aerial photography at large scales was selected primarily for this purpose. This is considered the first stage of a multistaged sampling procedure of herbland and shrubland vegetation potentially capable of development from the ground to space vehicle platforms.

Anscochrome D-200, rated at ASA 200 and exposed with a 1-A skylight filter, was selected for the regular color film. Kodak Ektachrome Infrared Aero film (type 8443) was used to obtain a record of the reflectance of herbaceous and shrubby species beyond the visible spectrum. It was exposed at an ASA rating of 160 with a minus blue (Wratten 12) filter to sense in the 0.5 to 0.9 micron wavelength band. The selection of this film type was made on the basis that discriminate differences between herbaceous and shrubby species might be more discernible in photography registering reflectance in the near infrared.

Since we did not know the scale of photography that might best be useful for discriminating individual species and since the density (number per unit area) of individual species ranged from rare to abundant within and among the test locations, the largest possible scales that could be

Table 1. Location, Date, and Scale of Aerial Photography 1968

Location	Date and Scale June 1	July 2	August 5	October 1[1]
Black Mesa		1:600 1:2400	1:600 1:2400	1:600 1:2400
Manitou	1:600 1:2400	1:600 1:2400	1:600 1:2400	1:600 1:2400
Kremmling	1:600 1:2400	1:600 1:2400	1:600 1:2400	
McCoy	1:1200 1:2400	1:1200 1:2400	1:1200 1:2400	

[1] The October mission had not yet been flown at the time of preparation of this report.

Figure 14. Aero Commander 500-D used to procure the photography.

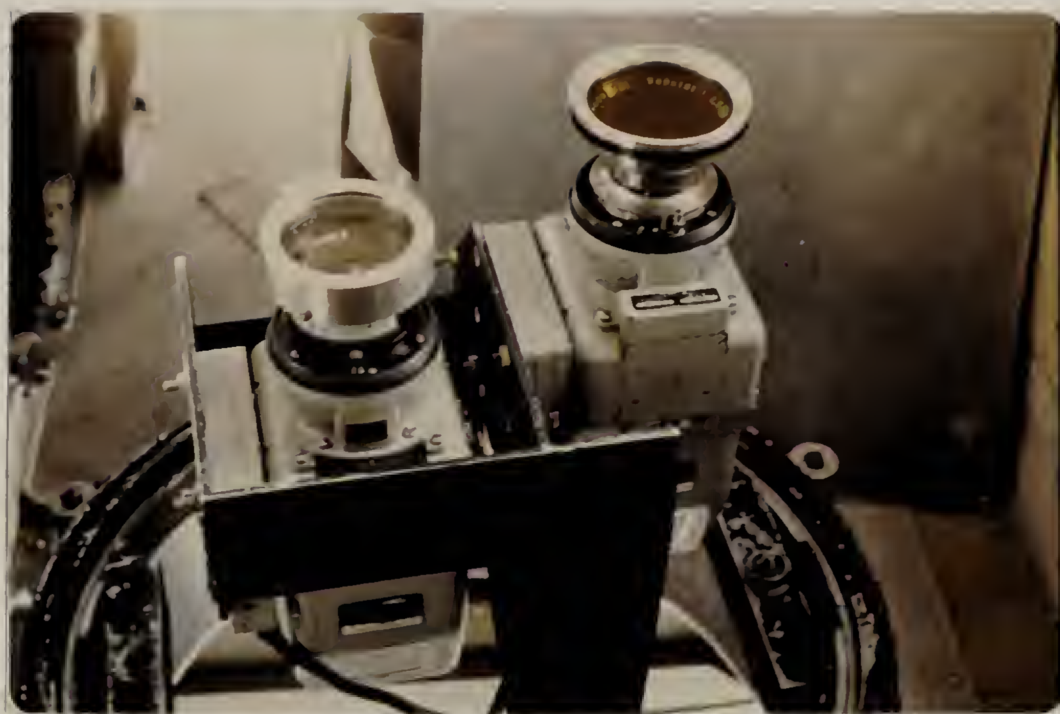


Figure 15. Twin-mounted 70mm aerial cameras used to obtain simultaneous photography with two different film types.

were impulsed simultaneously by an Abrams CP-3 intervalometer to provide identical photo coverage on the two film types. This eliminated photographic variables associated with time of day on the two films and provides for more valid comparisons to be made. The shutter speeds were set at 1/2000th second, with the airplane flying at 100 miles per hour, to reduce image motion and obtain 60 percent overlap for stereoscopic coverage. All films were processed at the photo laboratory of the Pacific Southwest Forest and Range Experiment Station Remote Sensing Project at Berkeley, California, to avoid possible discrepancies in development. The finished product was a continuous roll of transparencies to avoid potential loss of resolution when processing includes production of prints.

RESULTS

We are in a position to report on partial finding only, and these aer based primarily on the prefatory investigations conducted in 1967 as mentioned in the INTRODUCTION. Summarization and analysis of ground-truth data are still in progress and are required prior to relating photo measurements to ground measurements. Only the June and July 1968 photographs are available at this time. Due to camera and/or light meter malfunctions or film irregularities, the June 1968 photographs are not typical. Therefore, the August and October photographs are required before meaningful comparisons can be made.

Plant Species Identification

Identification, the differentiation and grouping of objects based on selected characteristics, involves classification. Therefore, the identification and hence the classification of a plant species in the

aerial photographs used must be based on characteristics of that species as imaged by the remotely placed sensor and not by the usual taxonomic characteristics of the species as viewed first-hand. Consequently, some basic principles of classification in relation to the selection of differentiating characteristics to separate species as imaged in the photography must be considered in order to assess the relative usefulness of the two types of photographs procured at different scales and seasons. These principles include:

1. The differentiating characteristic must classify all individuals in a single population.
2. Greatly different groups of individuals require different differentiating characteristics at the same level of abstraction.
3. All groups of objects of the same category of a single population should be based on the same characteristic.
4. A differentiating characteristic in one category must not separate like things in a lower category.

A preliminary, dichotomous photo interpretation key has been developed using the color infrared photographs of the Black Mesa location procured on August 24, 1967, at a scale of 1:920. Earlier (June) or later (November) photographs were not used because the film was exposed under adverse weather conditions and therefore was not representative. July photographs were not included because all vegetation was at the peak of growth which in turn provided minimum probabilities of differentiating imaged species. At this date with the infrared color photographs, all species appeared bright red on the processed film.

In developing the photo interpretation key, the photographs were examined under a 2-4 power lens stereoscope to enhance the resolution by providing a three-dimensional enlarged model of adjacent transparency pairs. Four major identification features of imaged species were used for the key: general color, foliage pattern and texture of individual species, relative size, shape and shadow of the species, and specific colors.

The general color categories were green, yellow, red, blue, purple and white . Some of the plants appeared to fit two or more of these general categories. For example, a plant that appeared reddish-green may seem more reddish in one frame and more greenish in the next. To facilitate identification, plants with such color combinations were differentiated using the most common color. For plants where the given color category was not distinguishable, a decision was made using one of the general colors. At first, such situations were not readily resolved, but with practice and instruction, the interpreter learns to make the distinction.

The specific colors mentioned in the key attempt to describe the plants as accurately as possible in basic color terminology; i.e., reddish-brown rather than rust colored. An attempt was made to relate image color to Munsell Color notations. This has not yet been successful because of the inconsistency of interpreters to simultaneously assess the color viewed in the transparency to a color viewed directly from a color chip. Also, the apparent plant color may appear to change due to site differences, associated vegetation and background.

Five class categories of foliage pattern and texture were used in the key. These class characteristics result from the integrated appear-

ance of the external morphology of the plant as observed in the transparencies such as kind of branching and leaf size, shape and arrangement. When these features are viewed from a distance or otherwise become too small to differentiate, they form a texture.

The five basic classes of foliage pattern and texture of individual plants used include: large clumping, loose or tight (Fig. 16); small clumping, loose or tight (Fig. 17); granular, loose or uniform (Fig. 18); distinct fine or indistinct fuzzy (Fig. 19); and rosette-like (Fig. 20).

These features of pattern and texture appeared to be fairly reliable identification characteristics. Situations occurred, however, when they were difficult to differentiate such as when the species under examination occurred in dense stands of associated vegetation. In these cases, examples of the same species were identified in the transparencies where the species occurred in less dense stands and then related to the prior condition.

The fourth general category used for development of the key was relative size, shape and shadow of the species. These class characteristics appeared most useful when comparing a particular species to associated vegetation in the immediate area viewed in the transparencies.

Size, as used in the key, is in relation only to those plants in the immediate vicinity of the plant in question. Large, medium, and small were the classes used and denote both breadth and height. Descriptive terminology for plant shape is so far limited to irregular and entire. Both of these characteristics, size and shape, vary widely for a particular species. This is due to the variety of age classes which occur in close proximity of one another, the natural irregular growth characteristics of

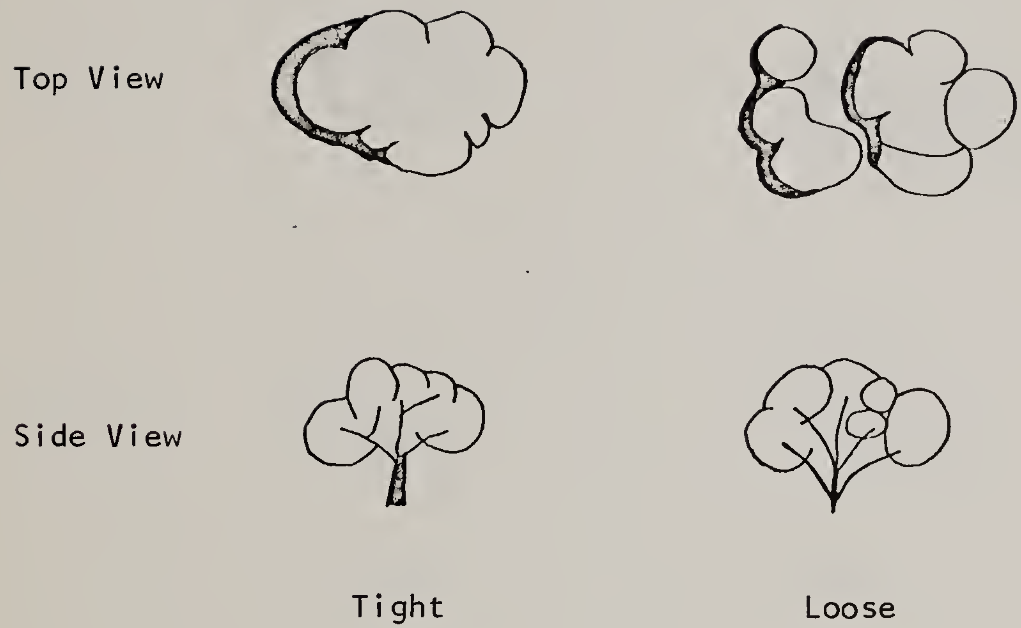


Figure 16. Large clumping of individual species as viewed from the top and side. These clumps are either tightly or loosely composed.

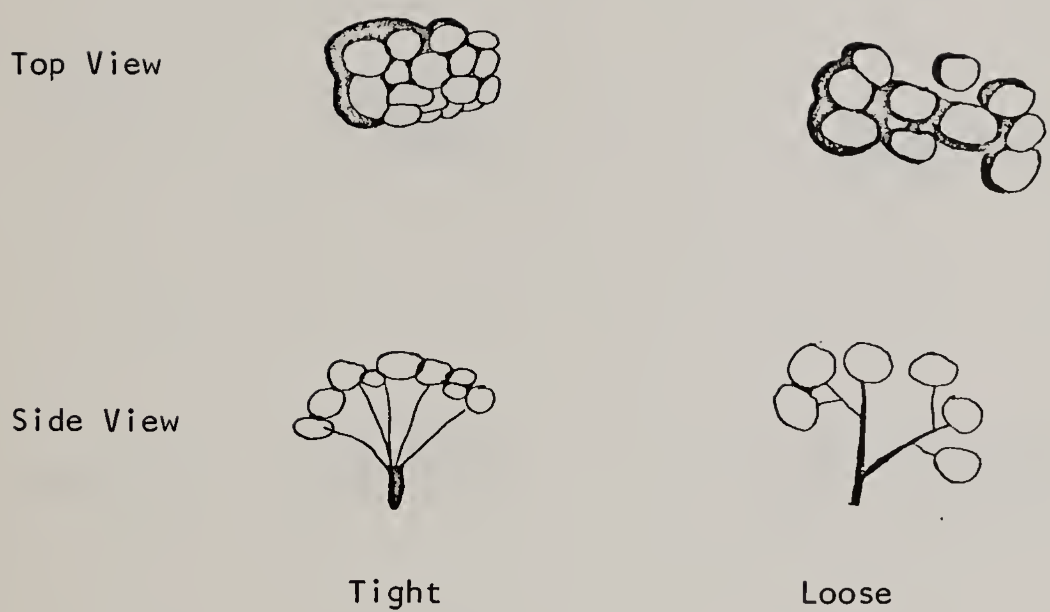


Figure 17. A plant with many small branches appears from above as being composed of many small clumps, tightly or loosely arranged.

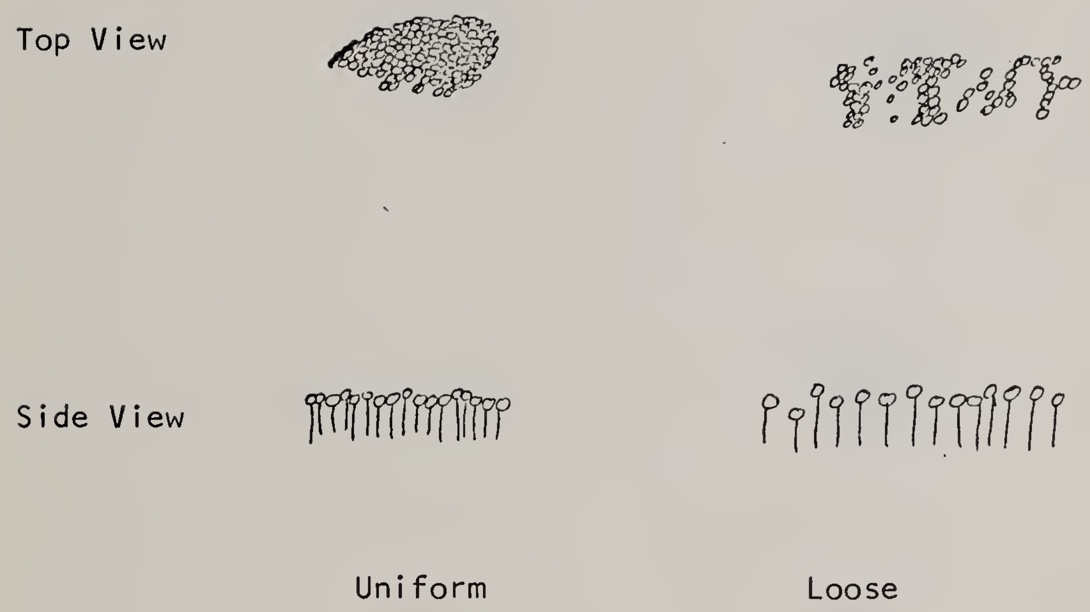


Figure 18. A plant with a granular appearing texture appears uniform or loosely arranged as viewed from above or from the side.

Figure 19. The fine texture of an apparent individual plant results from a clustering of many thin stemmed plants or many thin stems of an individual plant. This characteristic is used primarily for grass plants.

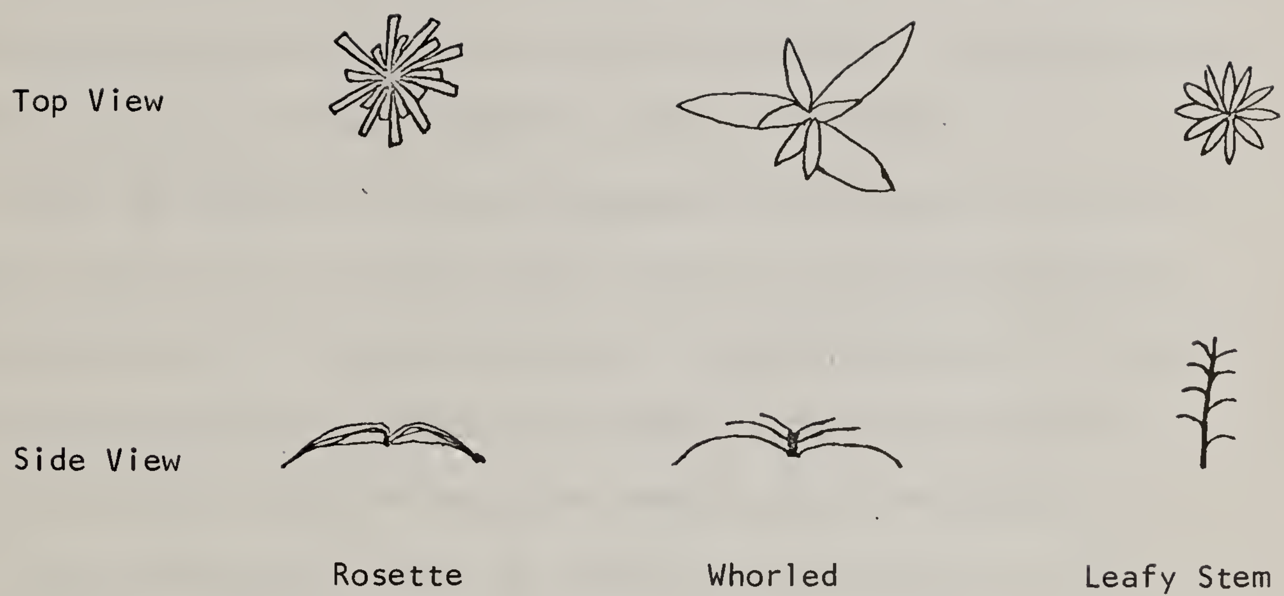


Figure 20. The rosette-like pattern of the foliage of individual plants, when viewed stereoscopically, appears as an irregularly shaped form with linear dimension only (rosette), 3-dimensional with greatly varying leaf size forming an irregular shape (whorled), or 3-dimensional with similar leaf sizes forming a regular shape (leafy stem).

many herbaceous and shrubby species, and events such as foliage removal or trampling by animals which alter the apparent size and shape of the plants in space and time.

Shadow, which is related to plant size, density and kind of associated vegetation, and time of day of photography, appeared to be a useful characteristic for the identification of some species. A medium or large-sized plant with tight foliage has a good solid shadow. In comparison, a plant with fine loose foliage produced a negligible shadow.

It must be recognized that the character states used to identify a particular species will vary from plant to plant as a result of differential growth forms within a species as well as disturbance of the species caused by animal grazing or trampling. However, character descriptions used to discriminate a species described most commonly the species as viewed in the photographs. Since the descriptive features are still tentative and in need of refinement, since selection of stereograms is not complete, and since inclusion of other dates of photography has not been possible, results of photo interpretation tests are not available yet. We hope that results of these tests, to be included in subsequent progress reports, will identify the "best" film type, season, and scale of photography for identification of herbaceous and shrubby species.

The following key will provide the reader with an appreciation of the potential possibilities for remote detection and identification of herbaceous and shrubby species using large scale color infrared photography:

1. Plants with detectable flowers

2. Flower stalks appear tall to medium in height; basal foliage may be visible or may blend into an inconspicuous mass with the associated vegetation.

3. Flower stalks tall in bright, white, prominent heads that look like cottonballs; basal foliage, when visible, appears as a dark, dull grennish color----------- _Achillea_ _lanulosa_

3. Flower stalks medium height with flowers as white or yellowish specks; basal foliage appears reddish-green when distingable---------------------------------- _Erigeron_ _macranthus_

2. Individual flower stalks indistinct; flowers appear as tiny white specks; individual plants not visible, but appear as granular, small to medium sized, irregular shaped clusters; foliage medium green color tinged with lavender------------ _Chrysopsis_ _villosa_

1. Plants with no detectable flowers

4. Plants with regular to irregular rosette or whorled shapes

5. Foliage distinctly whorled; leaves large and distinct, good shadow; bright lavender color-------------- _Swertia_ _radiata_

5. Foliage rosette in form, leaves small and somewhat indistinct, no shadow; dull lavender to light purple color or white with a greenish tinge.

6. Leaves dull lavender to light purple with whitish tips--- _Helenium_ _hoopesii_

6. Leaves whitish and indistinct (appears as plant litter) but greenish tinge on the edges------------- _Taraxicum_ _officinale_

4. Plants not with irregular or whorled shapes

7. Plants medium to large in size, casting a fair to good shadow

8. Foliage very fine and compact; bluish grey to greytinged with pink-- _Artemisia_ _tridentata_

8. Foliage clumpy or granular

9. Foliage in small to large loose clumps; irregular shape; maroon, purplish red, greenish red, or reddish-charcoal color apparently depending on size and age of plants-- _Chrysothamnus_ _parryi_

9. Foliage in small clumps to granular; entire; pinkish-red, greenish-red, or orange-green------------ _Potentilla_ _fruticosa_

7. Plants smaller and with little or no shadow

10. Foliage granular

11. Foliage loosely granular; gold color; may occur in large groupings -------------------------------- _Geranium_ _fremontii_

11. Foliage tight granular; usually appears as individual plants; dull to reddish lavender-------------------------- _Lupinus_ sp.

10. Foliage fuzzy

12. Individual plants indistinct; appears as a mottled greyish-green unit------------------------------------- _Poa_ _pratensis_

12. Individual plants appear as a tuft

13. Plants distinct, medium size, with entire shape; indistinct shadow; light pink, reddish green or dull orange, frequently with a whitish to light brown tinge. Caused by standing old growth -- _Festuca_ _thurberi_

13. Plants indistinct, small with no apparent shadow; light to medium green with a faint pinkish tinge------------- _Festuca_ _idahoensis_

Many other plant species occur in the area and are imaged in the photographs from which the preceding photo interpretation key was developed. However, the characters and character states to be used for their discrimination need to be more thoroughly defined or even discovered.

Plant Species and Community Measurements

The full use of aerial photography or other sources of remotely secured data can be realized when techniques are developed for rapid data reduction and processing. Langley (1965) has explored these possibilities using panchromatic aerial photographs. Doverspike et al. (1965) conducted exploratory tests to identify tree species and various land use classes from 70mm color aerial photography (scale 1:1188) using a General Aniline and Film Corporation Ansco Model 4 automatic recording microdensitometer. Results of these researches indicate the strong possibilities of automating the identification and quantification of shrubby and many herbaceous species and to distinguish between plant communities provided sufficient detailed ground truth of important parameters are procured.

These kinds of data have been secured and include amount (measured foliage cover) and kinds (plant species) of vegetation and ground surface characteristics along the established ground transects described under the METHODS section. As previously described, these transects were so marked on the ground that their positions can be easily seen in the aerial photographs. These ground truth data are currently being summarized in preparation for being correlated by multiple regression procedures with data secured from the photographs with scan-line readouts generated by a General Aniline and Film Corporation Model 650 microdensitometer (Fig. 21). The machine is located at the Pacific Southwest Forest and Range Experi-

Figure 21. General Aniline and Film Corporation microdensitometer with a Honeywell "Electronik" Strip Chart Recorder attached. This equipment produces a density trace of a predetermined scan line marked in a transparency. The density output is related to the imaged object in the aerial photograph.

ment Station in Berkeley, California. This instrument is connected in-line with a Honeywell "Electronik" Strip Chart Recorder as modified by GAF. The resultant readout recorded on the chart provides the combined effect of precision linear measurement and densitometry from the photography. An example of this readout is shown in Fig. 22 which illustrates the scan-line readout across an open grassland-aspen stand-spruce stand using a color infrared transparency exposed at 1:4600 scale on August 24, 1967, over the Black Mesa test location.

In general, the microdensitometer:

1. looks at a very small portion--as little as one micron in diameter--of a photographic image at spectral levels selected to be compatible with the sensitivity levels and dye component spectral characteristics of the photographic materials,

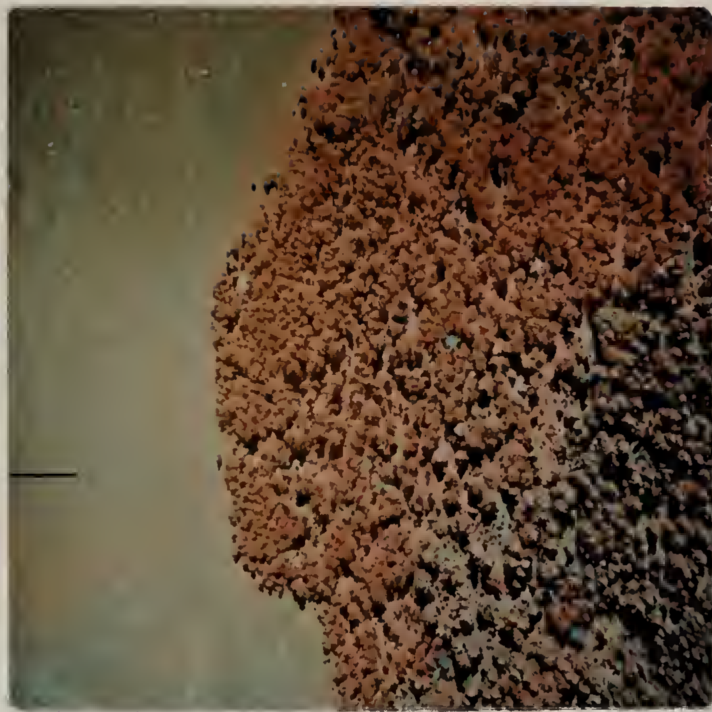
2. reads the optical density of the image by means of a scanning optical system and photo multiplier,

3. scans the sample at a uniform rate, as slowly as 0.05 to as rapidly as 50.0 millimeters per minute, and

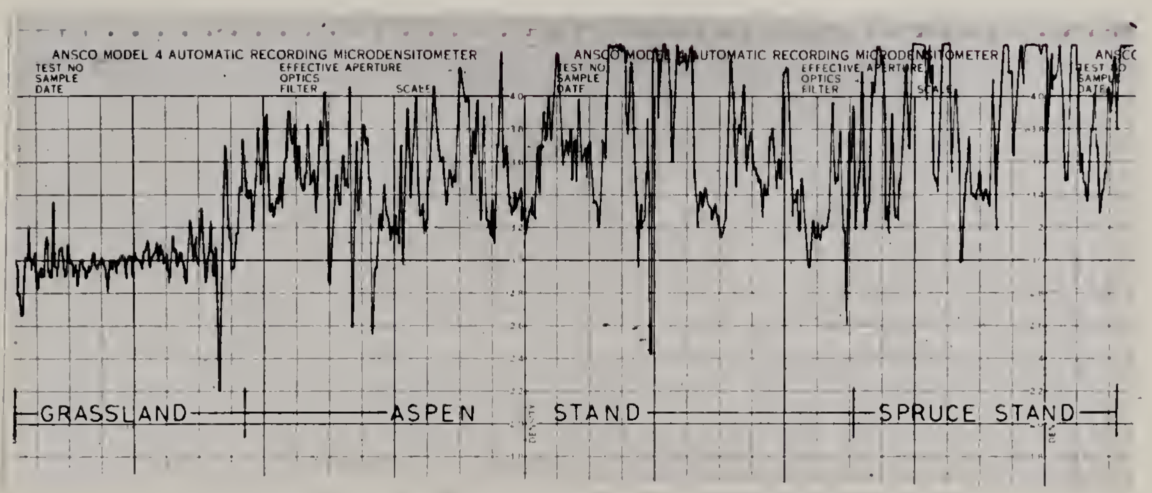
4. presents the data graphically on a strip chart or, when used with an analog converter, presents data digitally to a computer for reduction and analysis.

Work is underway and more finite research is planned to determine the "optimum" scan speeds-optics combinations for accurate and automatic identification of specific plant species and communities utilizing the microdensitometer. Specific results will be discussed in subsequent reports.

Use of the microdensitometer is restricted primarily to measurements



a.



b.

Figure 22. The scan-line output (b) from the microdensitometer reading across an infrared color transparency exposed over the Black Mesa test location at a scale of 1:4600 August 24, 1967 (a). The scan line extends between the black marks on the edge of the photograph. There is a sudden change in relative density between the grassland and aspen stand--a more subtle change from the aspen to the spruce stand. The low density readings in the timber stands are logs on the ground or individual tree trunks which are highly reflective of near infrared energy. The high density readings are tree crown shadows. The medium density readings are "sun spots" (openings within the forest canopy) and represent herbaceous understory.

made on the basis of film density ranges along a scan-line of a selected photograph. This procedure would greatly increase the speed of photo interpretation to determine what species are present and would quantify the amount of each based on foliage cover along a transect line representative of a small portion of the total area. However, estimates of plant height, density (numbers per unit area), or distribution might best be determined directly by an interpreter from the photographs using distance measuring devices or stereoplotting equipment. Research is planned to develop photogrammetric techniques to estimate these vegetation parameters and to relate the results to those produced by the microdensitometer where applicable.

DISCUSSION

Preliminary results of this study indicate that in general, large scale color infrared aerial photography might be more useful than color photography to identify many plant species in herbaceous and shrubby environments. This supports the findings of Carneggie and Reppert (1968). Many factors which affect image quality and interpretability, however, must be resolved prior to making recommendations favoring one or the other of these film types.

The angle of incidence of solar energy, both daily and seasonally, affects the reflective properties of the vegetation. Additional effects are attributable to the growth habit of individual plant species, the structure and denseness of plant communities, the topographic position of target objects, the background conditions of the target area (including the nature of the soil surface), the atmospheric haze and the degree of cloud cover. We have data which later will be reported upon with regard

to seasonal effects of the incidence of solar radiation. It must be remembered, however, that these effects are confounded by natural phenological cnanges of the kind of vegetation under study. The growth pattern of shrubby and especially herbaceous vegetation is much different from that of tree type vegetation during the growing season--more drastic changes in external morphology occur with the former kinds of vegetation.

We have no information on effects of sun angle or atmospheric conditions on image quality and interpretability of large scale photography. Therefore, both color and color infrared photography should be flown at one to two hour intervals on selected days of varying atmospheric conditions to isolate the effects of these phenomena. The seasonal timing for photography should coincide with that point in time offering the best possibility to detect and identify the greatest number of individual species. For the Black Mesa location, this would be in August. At Kremmling and McCoy, this would be in July. We are not yet certain when this time would be for the Manitou site.

As photo scale is reduced, ground resolution becomes less and the opportunity to detect and identify individual plant species decreases. However, the integrated reflectance of all species within a community or type should carry into progressively smaller scales of photography and even into photographic scales obtained from earth circling satellites. Ektachrome Infrared film equipped with a minus blue filter cuts off most atmospheric haze by blocking the blue end of the spectrum. Also, the infrared emulsions are sensitive to the near infrared wavelengths (0.7 to 0.9 microns) where vegetation is highly reflective. Therefore,

we need to secure progressively smaller scales of photography using this film type to develop multistaged sampling procedures for the potential identification and mapping of specific herbaceous and shrubby vegetation types. Satellite photography can be simulated through use of short focal length lens camera systems mounted in fixed-wing airplanes. If this procedure provides useful photographs, greatly improved qualitative and potentially quantitative information on herbland and shrubland resources could be extracted on a worldwide basis from photographs procured by earth orbiting satellites.

BIBLIOGRAPHY

Burks, G. F. and R. C. Wilson. 1939. A vegetation inventory from aerial photographs. Photogram. Eng. 5:30-42.

Canfield, R. H. 1950. Sampling ranges by the line interception method. Plant cover-composition-density-degree of use. U. S. Dept. of Agr. Forest Service. Southwest Forest & Range Exp. Sta. Report 4.28p.

Carneggie, D. M. and J. N. Reppert. 1968. Large scale 70mm aerial color photography--a potential tool for improving range resource inventories. Mss. accepted by Photogram. Eng.

Colwell, R. N. 1964. Aerial photography--a valuable sensor for the scientist. Amer.Sci. 52:17-49.

Colwell, R. N. 1961. Some practical applications of multiband spectral reconnaissance. Amer. Sci. 49:9-36.

Doverspike, G. E., F. M. Flynn and R. C. Heller. 1965. Microdensitometer applied to land use classification. Photogram. Eng. 31:294-306.

Harris, R. W. 1951. Use of aerial photographs and subsampling in range inventories. J. Range Manage. 4:270-271.

Heller, R. C. 1965. Aerial remote sensing in forestry. Proc. Soc. Amer. Forest. 1965:162-168.

Interagency Range Survey Committee. 1937. Instructions for range surveys. 30 pp. mimeo.

Langley, P. G. 1965. Automating aerial photo interpretation in forestry--how it works and what it will do for you. Proc. Soc. Amer. Forest. 1965:172-177.

Swanson, L. W. 1964. Aerial photography and photogrammetry in Coast and Geodetic Survey. Paper presented Cong. Inter. Soc. Photogram. Lisbon, Portugal.

U. S. Dept. of Agric. 1967. Agricultural statistics. Table 528, p. 424.

APPENDIX

The following is a list of Forest Service, U. S. Department of Agriculture, personnel who contributed to this study and represent a major salary contribution to it:

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